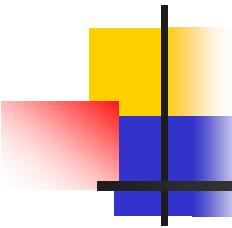


Electronics for the Liquid Scintillator OA Detector Opti

Summary of Cambridge Workshop
Feb 2004

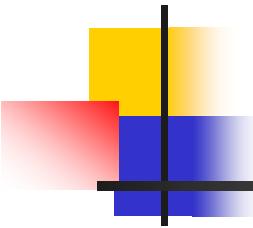


with help from: ANL, Cambridge, FNAL, Harvard, RAL, UMN



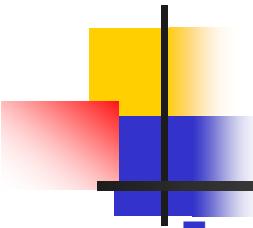
System Overview

- Physics Specifications
 - light level, noise
- APDs
- FE chip
 - Measurements (Leon)
- Readout Architecture
 - Analogue or digital pipeline
- DAQ system
- Timing System
- R&D for the next year



Requirements (I)

- Signal size
 - Sensitive to MIP from 14.4 m into detector
 - 25 pe
 - How many electrons is this?
 - signal 2500 electrons, noise 500e (250e)
 - Dynamic range (8bits)
 - 25 pe = 1 mip = 5 ADC
 - 4 (near/far) x 5 ADC x 5(no of mips) = 100 ADC
- Livetime
 - For beam physics
 - no deadtime around spill
 - For SN (Not proven) advantage*feasibility/cost=low
 - no deadtime for 10 sec ?
 - For calibration (cosmics)
 - maximize livetime out of spill (100 spills / 1sec)
 - Charge pulse



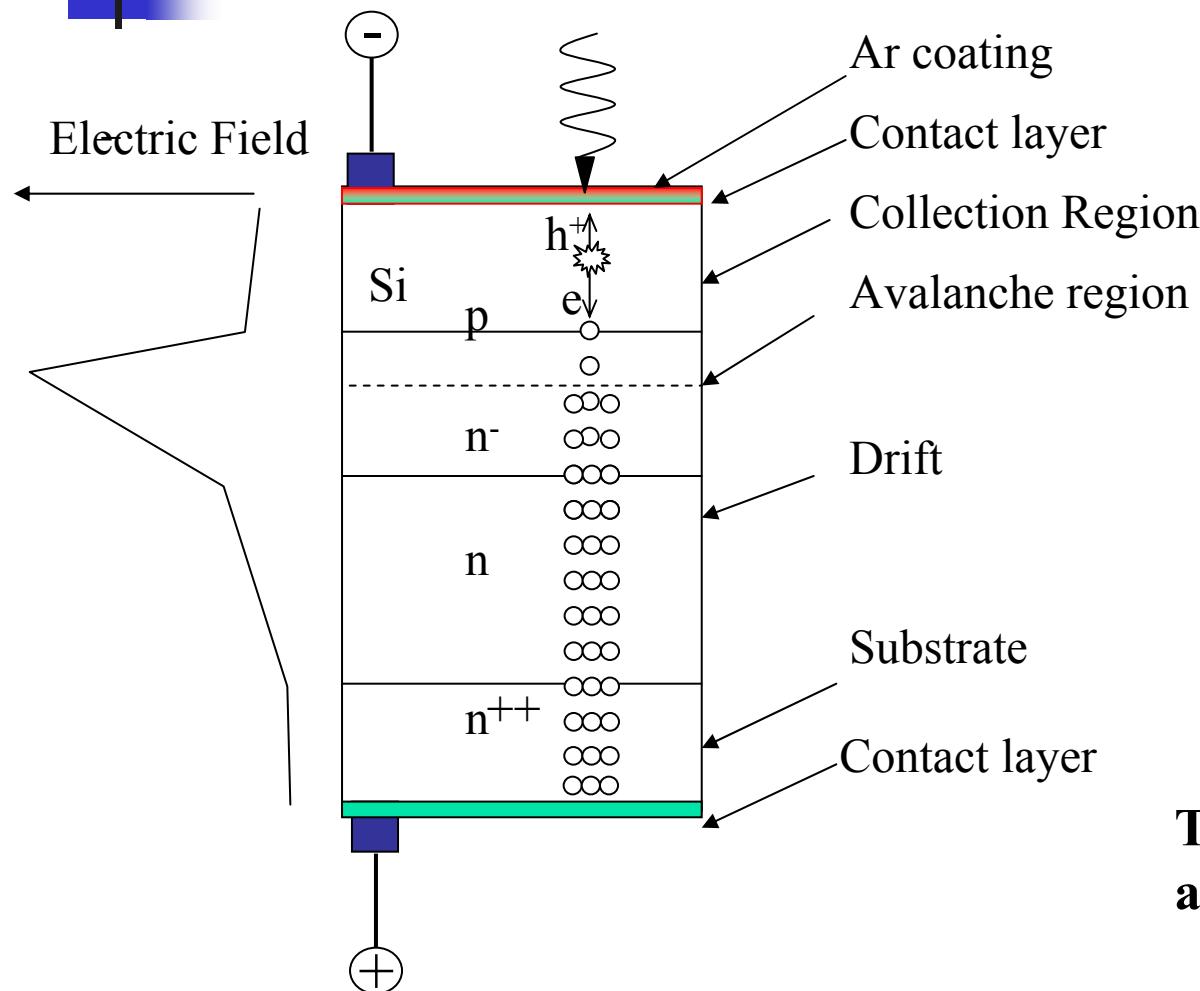
Requirements (II)

■ Possible Triggers

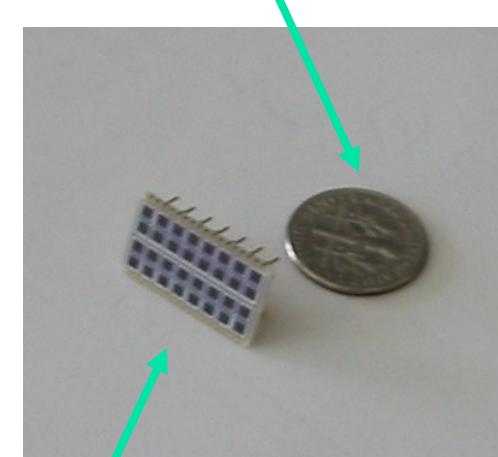
- External Trigger
 - Spill
 - SN
 - random
- Internal Trigger (not necessary)
 - neutrino interactions
 - cosmics
 - (SN)
- Near Detector compatibility ?
 - many overlapping events during 10 usec
 - Different electronics (fast)
- Failure rate
 - $<<10^{-5}$ day = 1 every 10 days
 - MTBF = $10^5 \times 24$ h

APD Operation

Roger is with Hamamatsu now

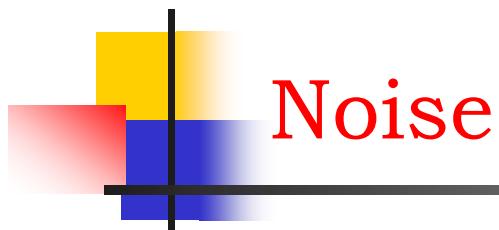


A dime (10¢)



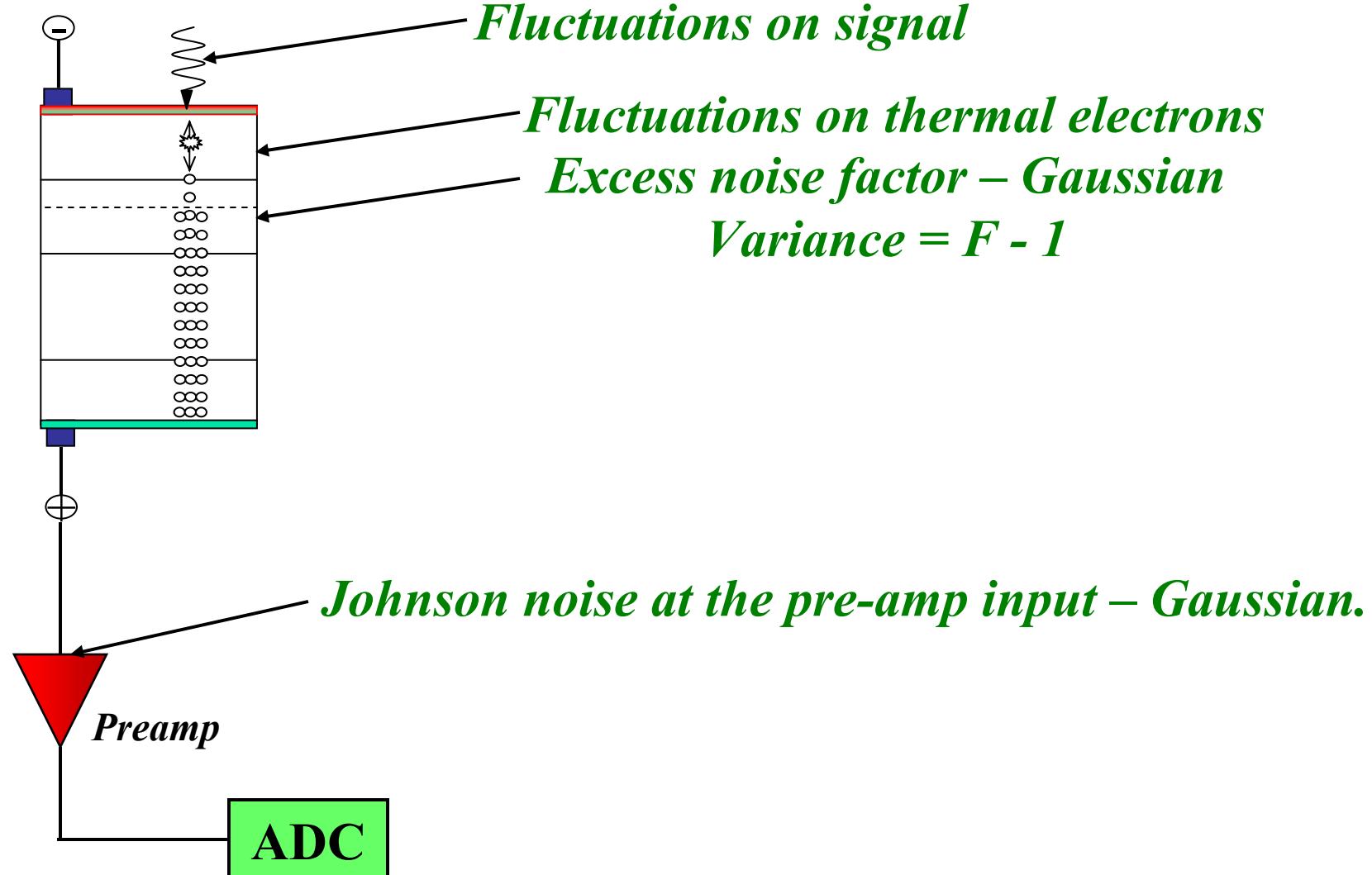
Two 16-channel
arrays

Electrons generated by the incident light are multiplied in the high field region at the junction.



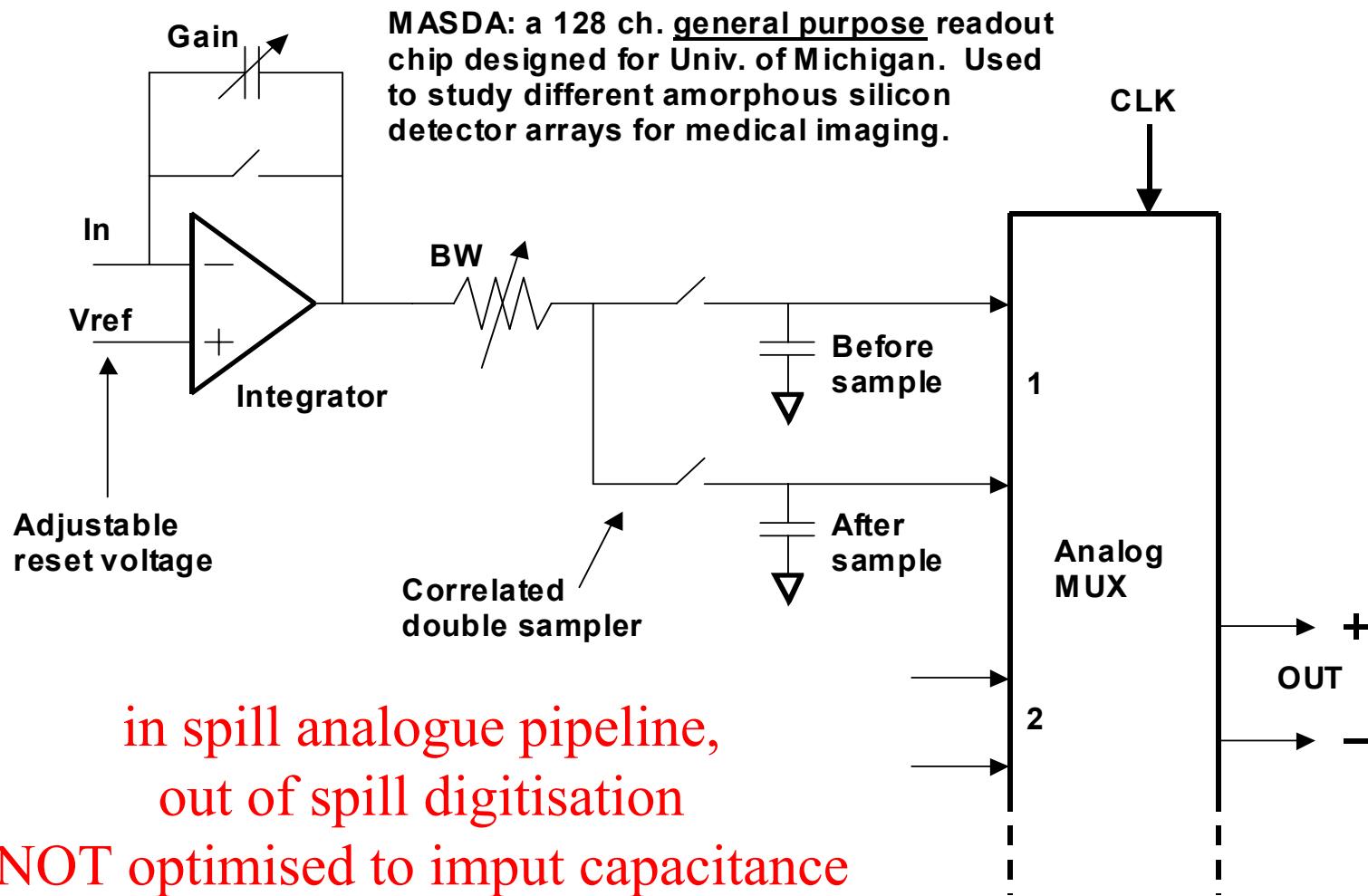
Noise

Noise Sources



Off Axis APD Readout (analogue)

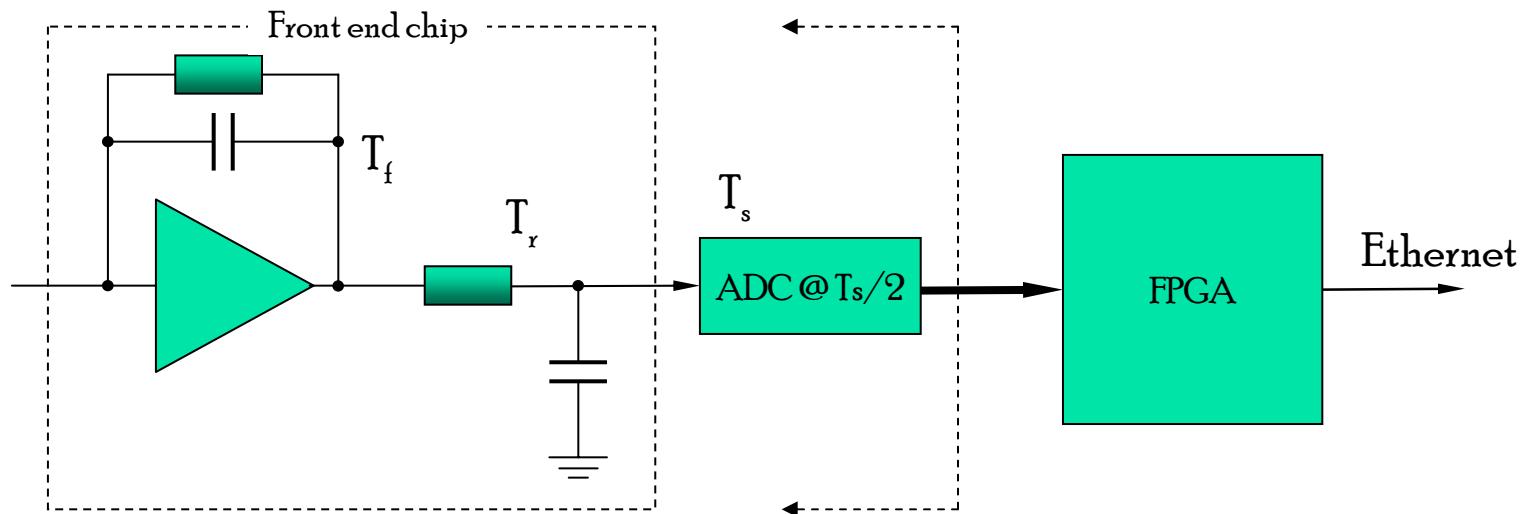
Proof of principle: existing MASDA chip (FNAL)



Off Axis APD Readout (digital)

Features

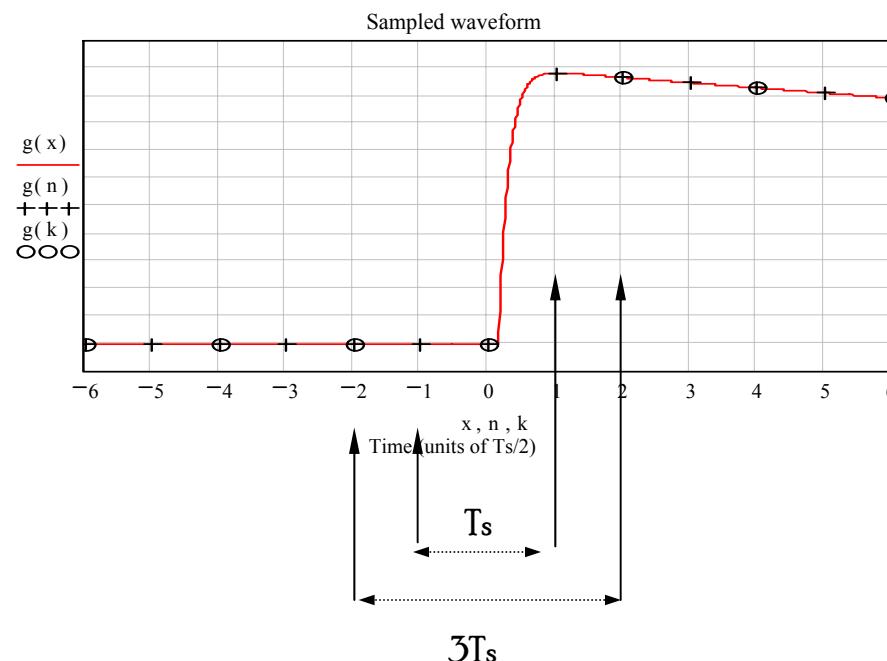
- Slowly leaking integrator: falltime constant $\sim T_f$
- Controlled risetime: T_r
- Multiple samples separated by $T_s/2 \rightarrow$ ADC digitizes data every $T_s/2$
- $T_r \ll T_s \ll T_f$
- Sample subtractions done on digital data within FPGA
- investigated by Harvard



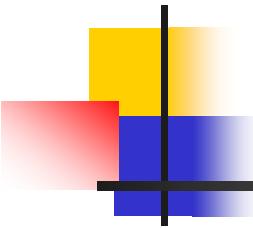
continues digitisation:
digital pipeline, regular reset

Multiple Correlated Samples

- Do not only sample pulse before and after APD signal
- Use multiple samples to reduce noise
- Digitisation and low noise amplifier



Simulations
by
John Oliver



Multiple Correlated Samples

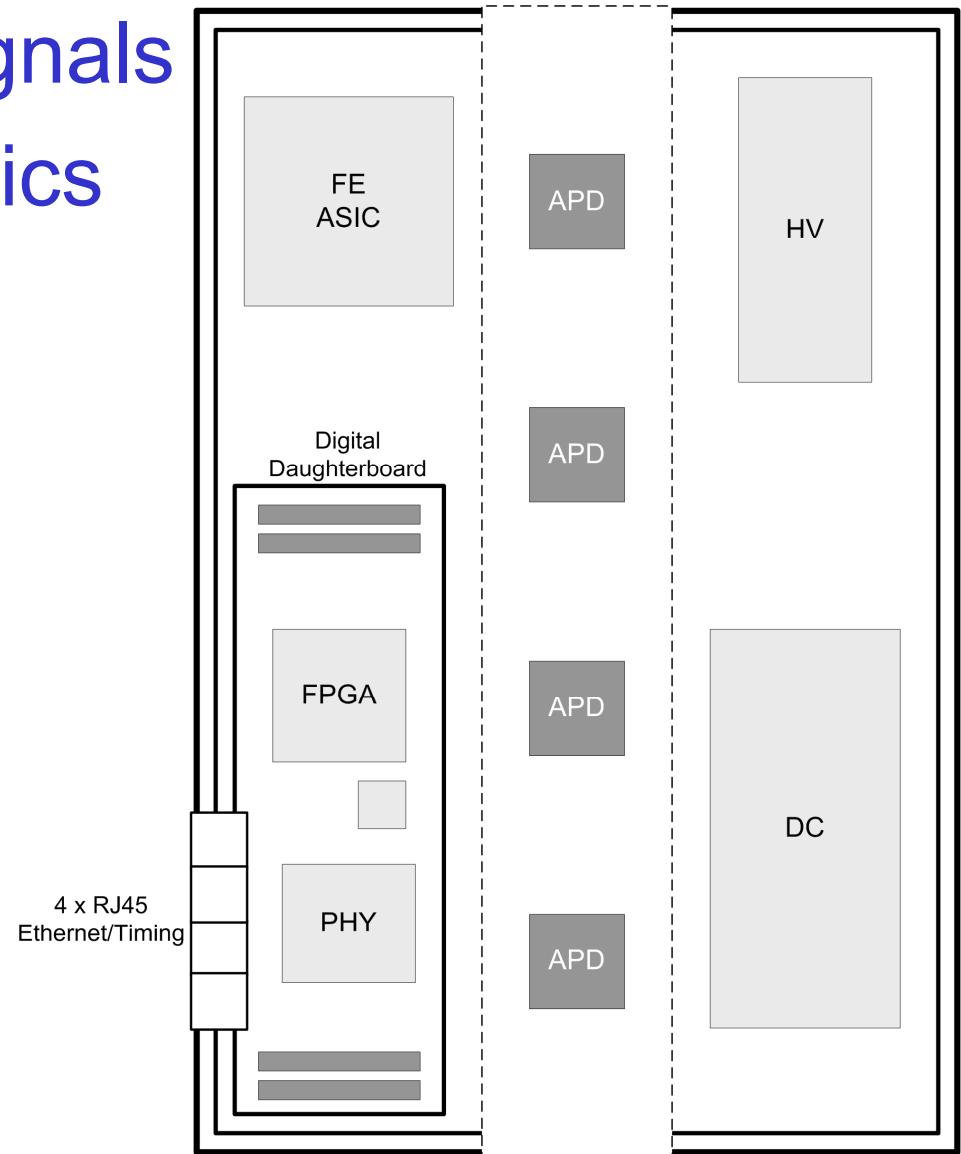
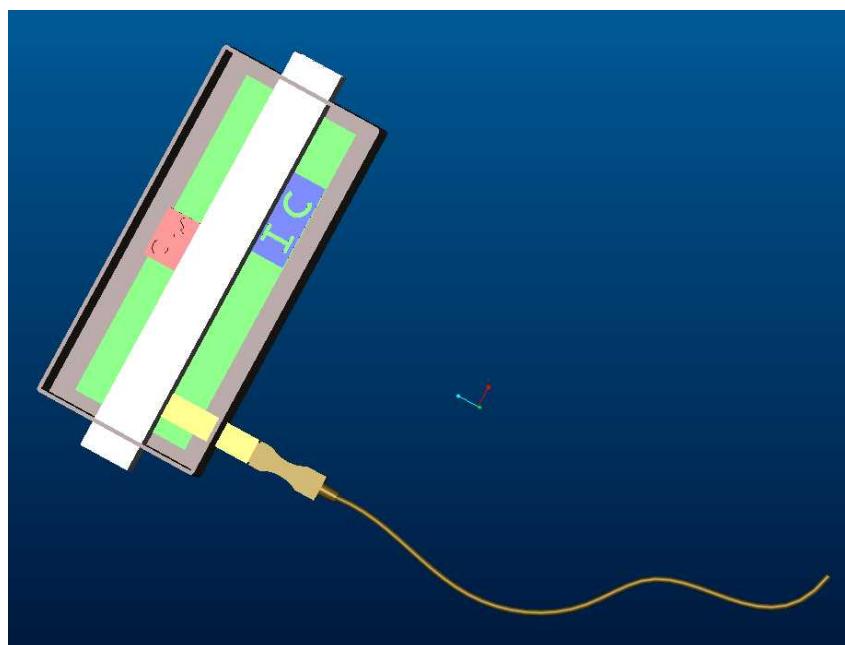
No of samples	Coefficients	Normalized sigma^2	Normalized sigma
2	1	1	1
4	$2/3, 1/3$	$2/3 = 0.67$	0.816
6	$6/11, 3/11, 2/11$	$66/121 = 0.55$	0.738
8	$12/25, 6/25, 4/25, 3/25$	$12/25 = 0.48$	0.692

Conclusion

- Using 8 samples, improvement is of order $\sim \sqrt{2}$
- Other optimizations possible: e.g. Use samples below & above optimal
- Noise improvement of > 30% or more are possible
- and best of all, its *free!*

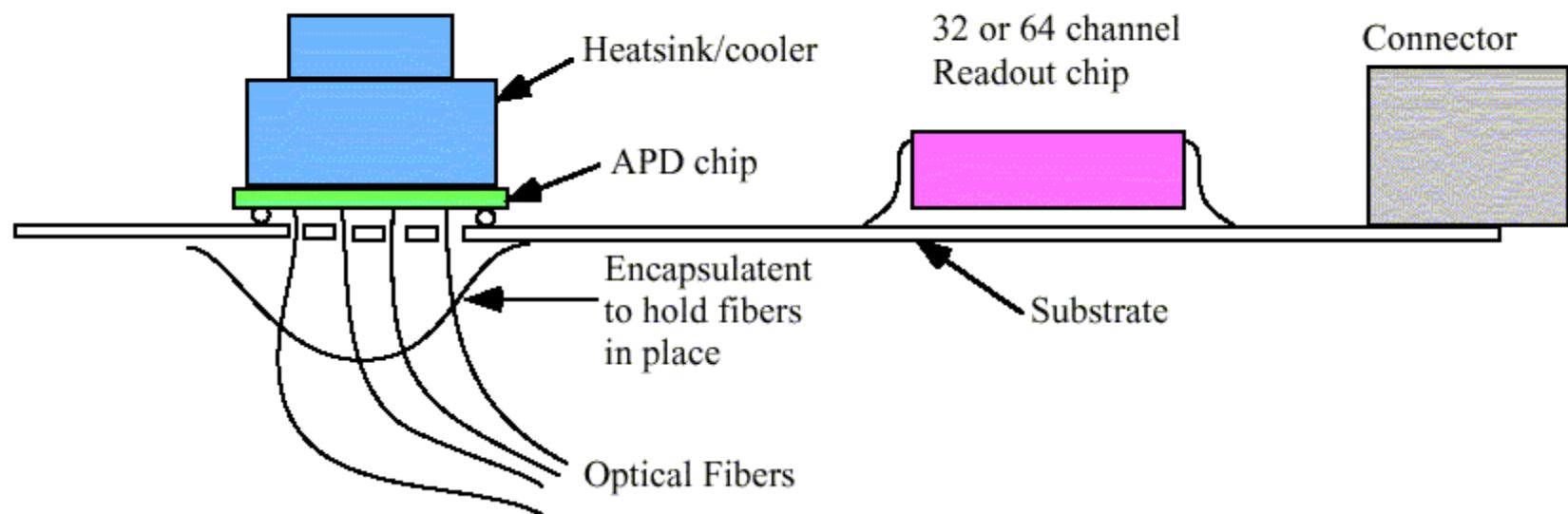
APD Box

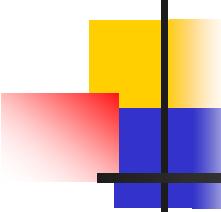
- Receive optical signals
- house FE electronics
- house digitisation
- interface to DAQ



PCB Sideview

- Put bare APD onto PCB
 - Flip-chip alignment to <<150 μm (Ray Yarema)
 - cool APD to 0 $^{\circ}\text{F}$

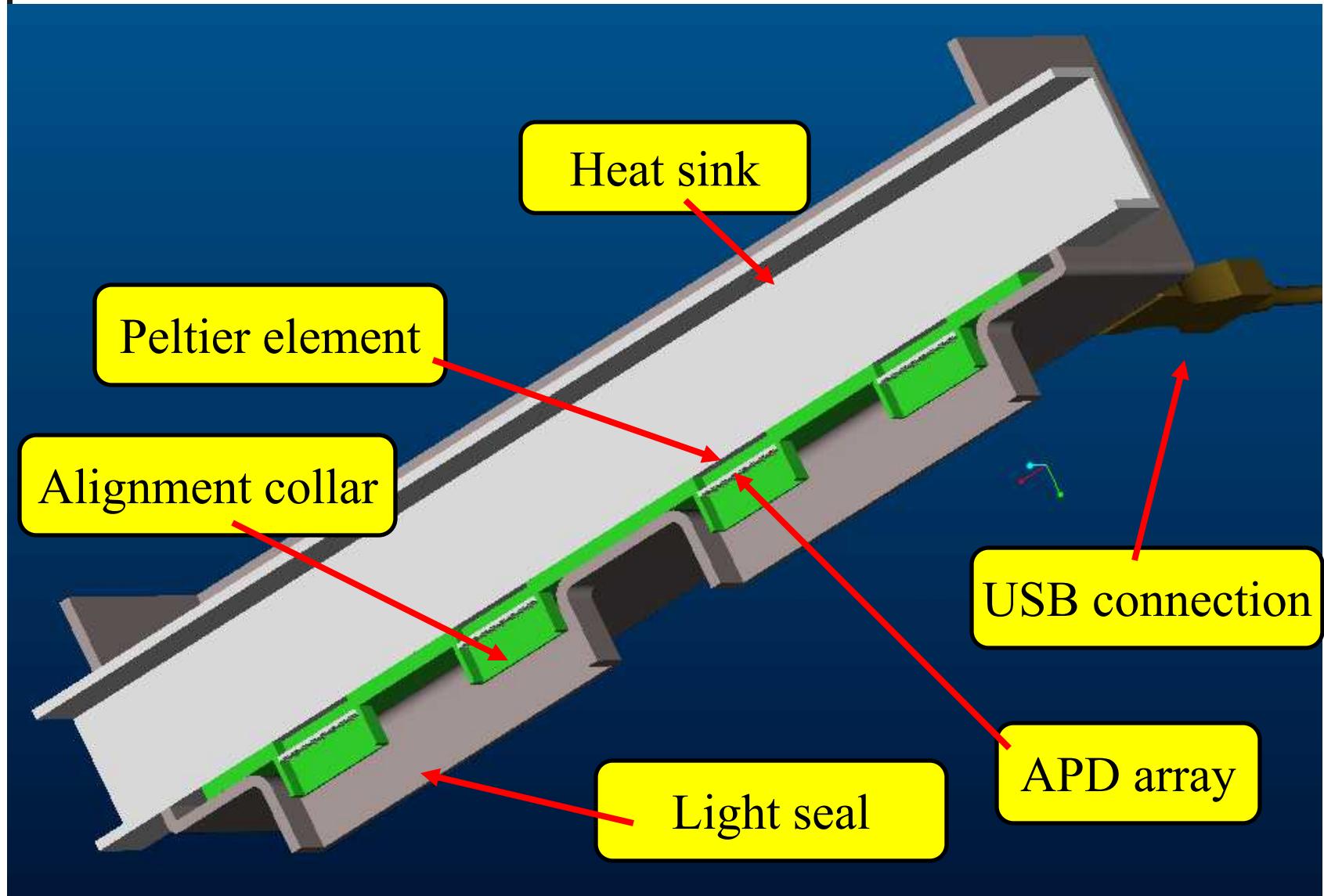


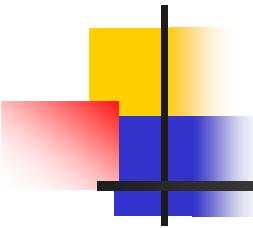


APD Box (II)

- Difficult!
- Needs dedicated electro-mechanical engineering (FNAL, UMN)
- To be considered:
 - optical & digital & LV connections
 - light tight
 - condensation
 - noise insulation (external & digital)
 - heat load from cooled APDs
 - ...

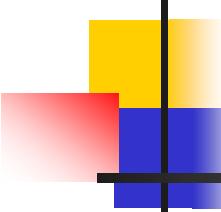
APD Box (design idea)





DAQ System (RAL)

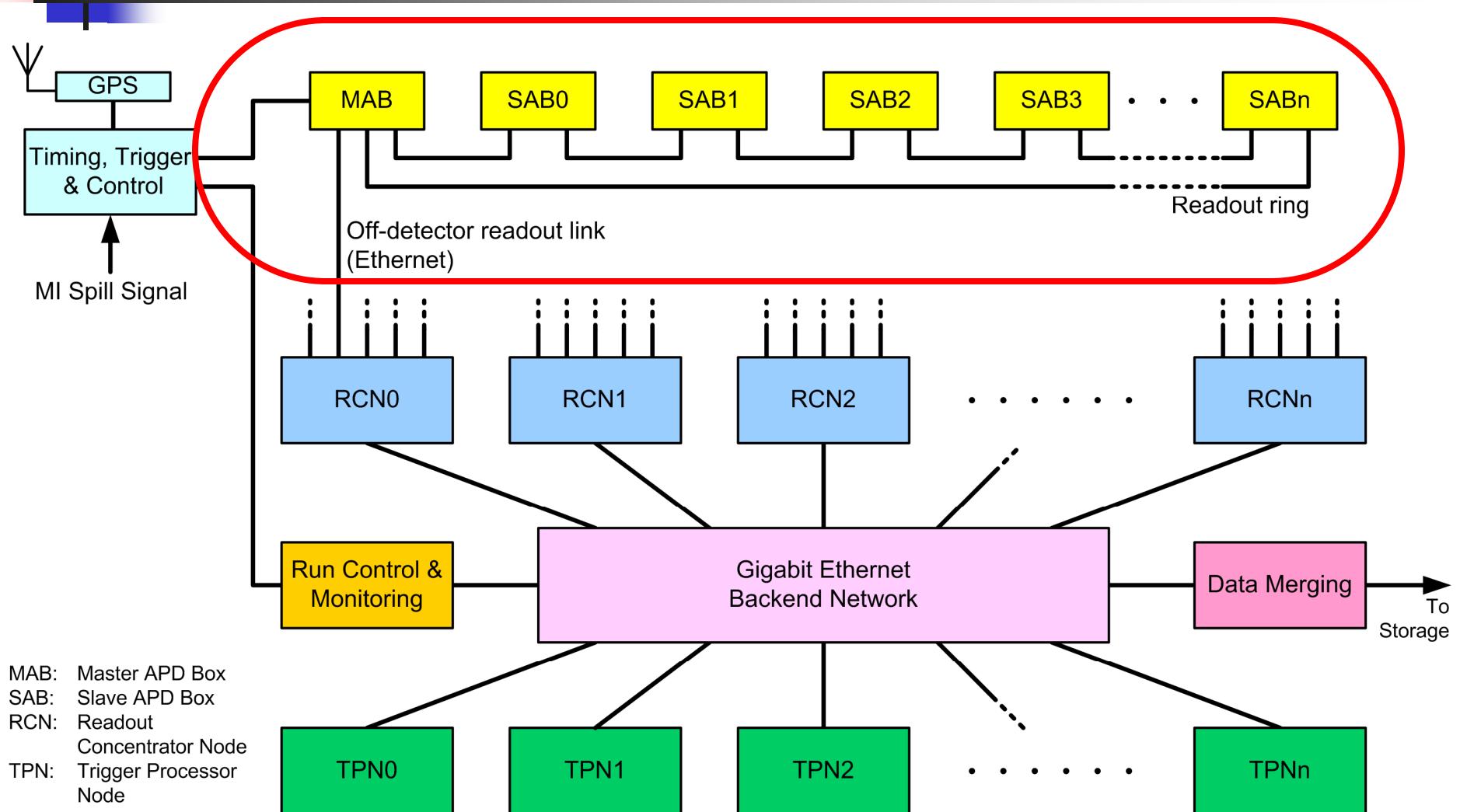
- Readout/DAQ is cost sensitive item
- Want:
 - Low cost per channel
 - Scalable, flexible system
 - Minimise off-detector links (major cost item)
 - Use standard technology where possible
 - Future upgrade paths considered
- Aggregate data from multiple APD boxes (96)
- Use (Gbit) Ethernet for off-detector links
- Total throughput scales with increased links
- COTS technology for DAQ backend



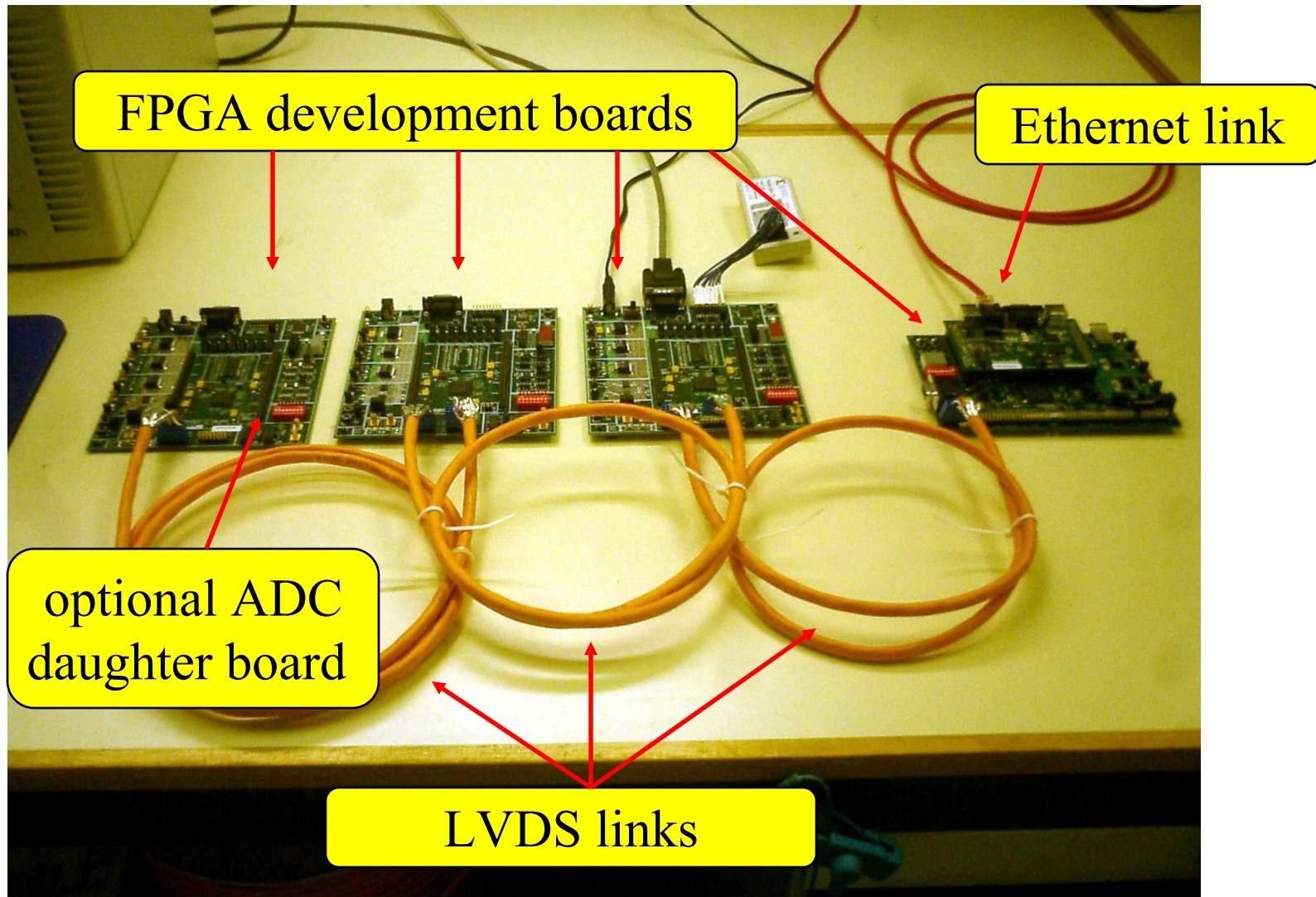
Input constraints

- 10,000 APD boxes
 - 64 channels / box (2 scintillator modules)
 - 8 Byte/channel @ 2 MHz
 - Continuous sampling, but ZERO suppressed
 - Assume spill = 20 μ s
- Data rate
 - Noise: $10^{-3} \times 2 \text{ MHz} \times 8 \text{ Byte}$, Signal: 0 Hz
 - 1 MB/s per APD box = 10 GB/s total raw data rate
 - 20 bytes per spill per APD box
 - 200 kBytes per spill
 - 100 Hz readout rate = **20 MB/s total rate**

Readout Rings

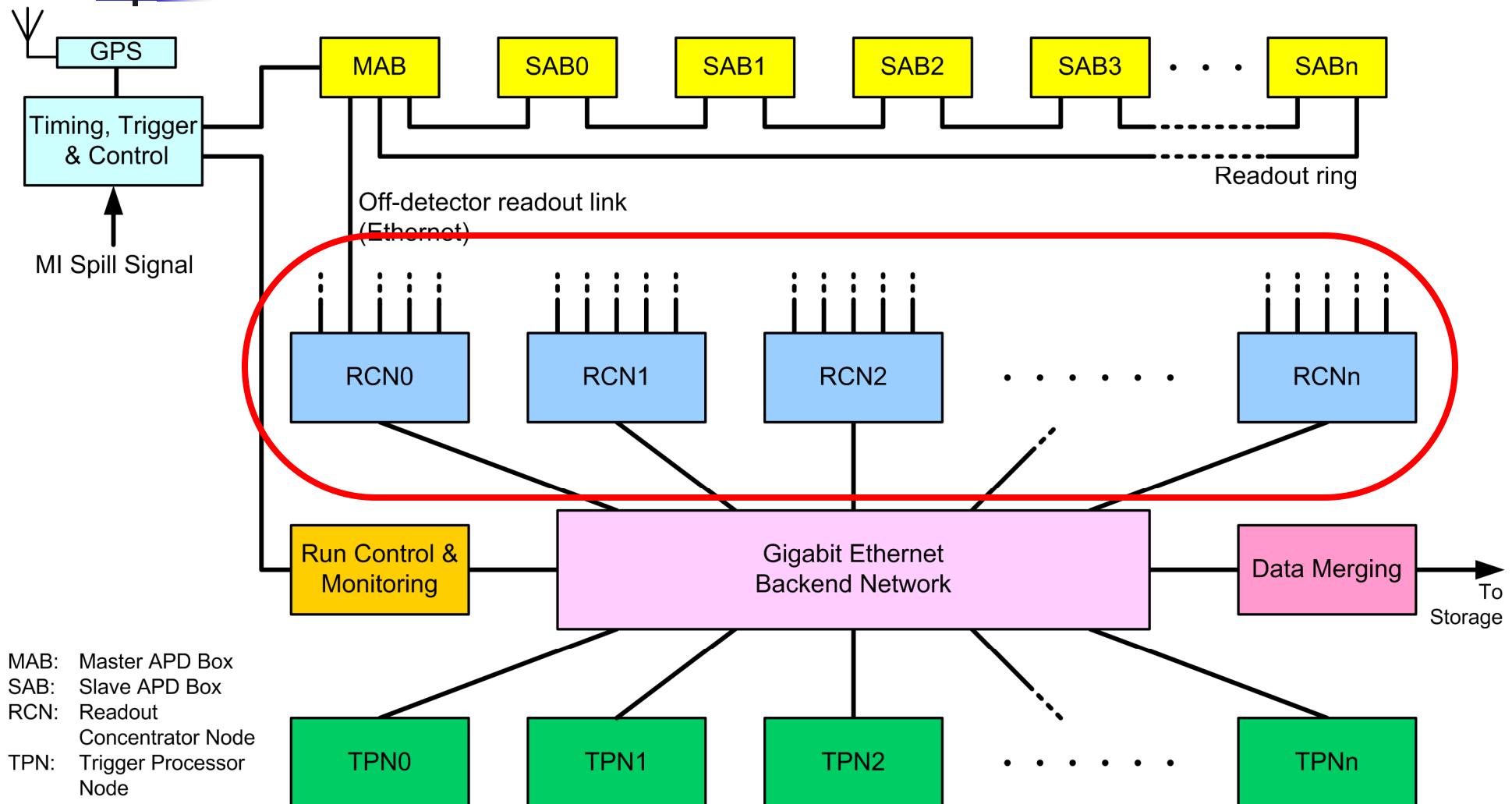


Readout Development @ RAL

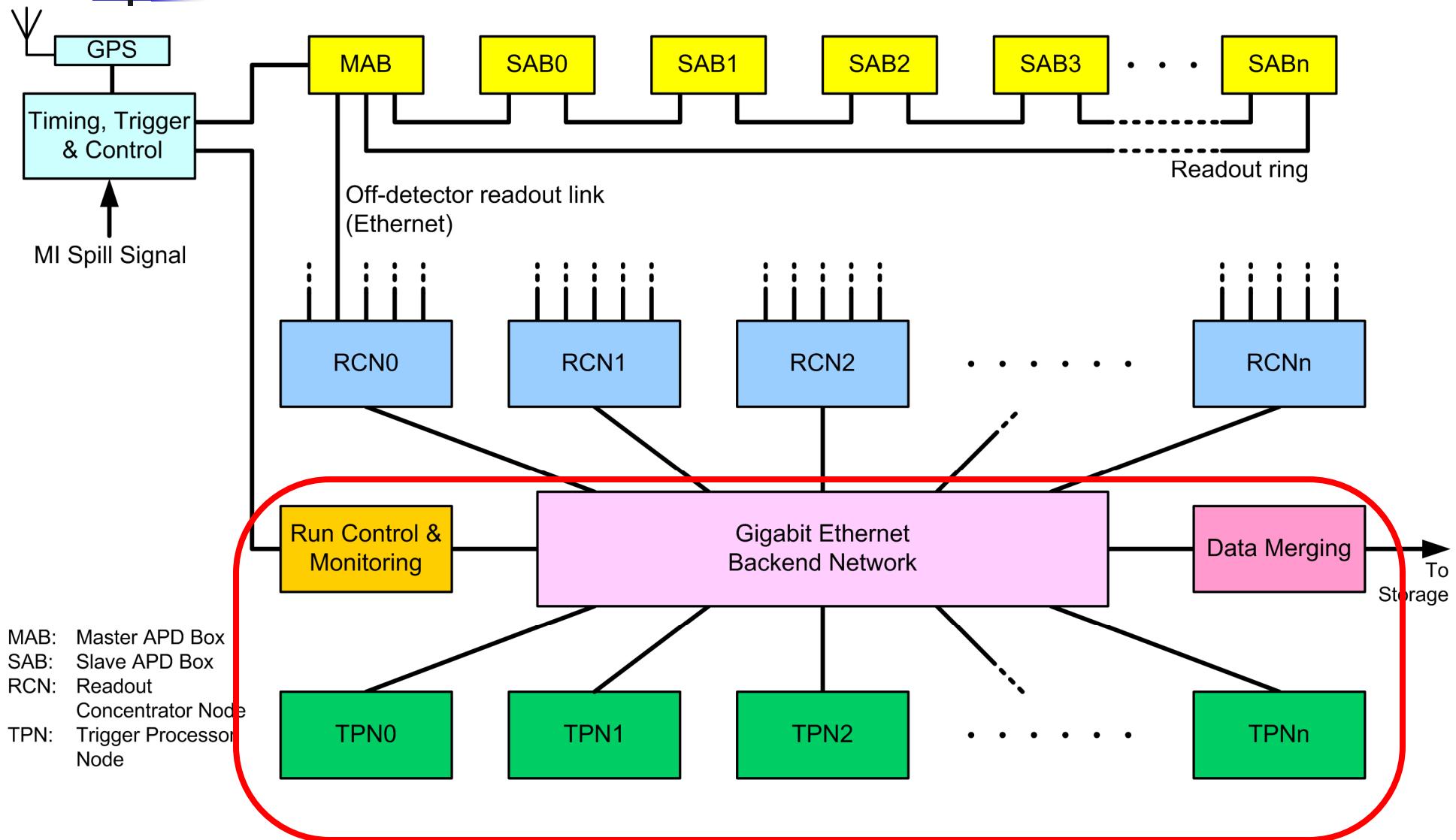


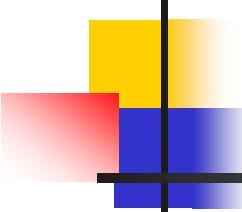
Readout Concentrator Node

PC with several network cards



DAQ Backend PC with Gigabit Ethernet





Clock & Timing System

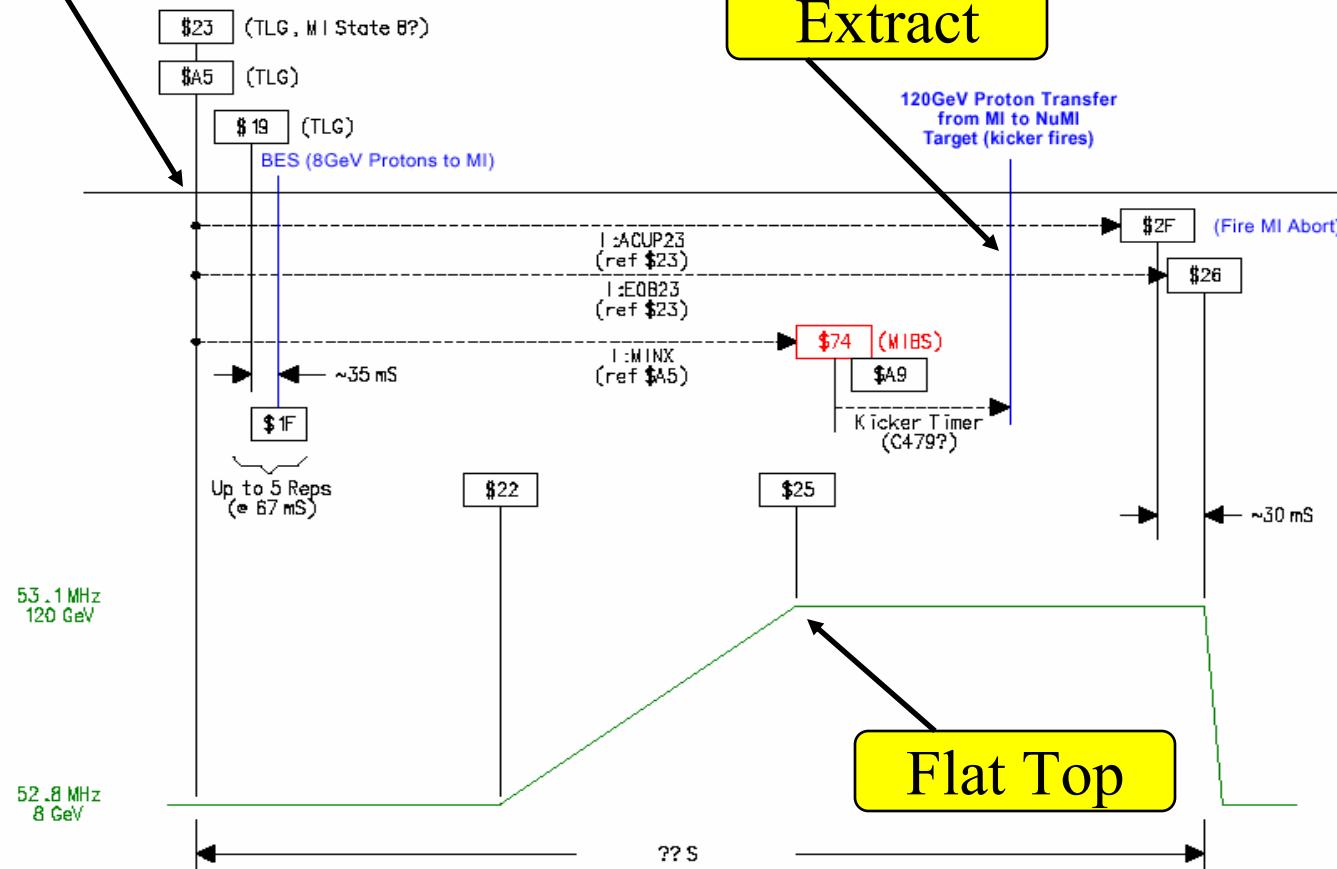
- FE needs timing to be synchronised across the detector
- FE may need accurate spill signal
 - in time: analogue pipeline
 - not to late: digital pipeline
- Need to get spill signal from FNAL to OA site
- Need to distribute clock around the detector.

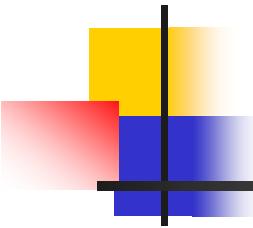
MI Timing Events (I)

Start Cycle

DRAFT Timeline for NuMI Cycles

Extract





MI Timing Events (II)

- Signals available

- Start of NuMI cycle (earliest)

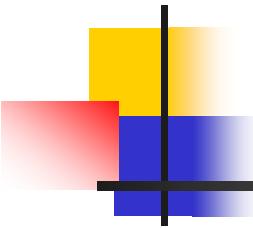
- ~1.4 sec in advance: \$23 & \$A5
 - predicts spill to within 1/60 Hz = 16.6 msec
 - spill-to-spill jitter: 20 μ sec

- Flat top

- ~0.4 sec in advance: \$25
 - spill-to-spill jitter: 10 μ sec???

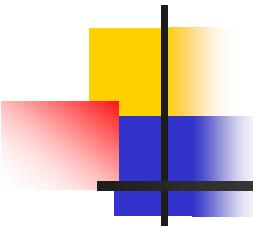
- Kicker fire (most accurate)

- few μ sec in advance: \$74 & \$A9
 - spill-to-spill jitter: nsec ???



Signal Transmission

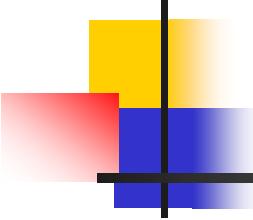
- Conventional HEP timing signal distribution at OA site
- But:
How do we get the spill signal to the detector?
- Options:
 - Internet (slow, ~0.5 sec latency ?)
 - Phone line (fast, msec latency)
 - Dedicated radio transmitter (fast)



R&D Plans for FY04.

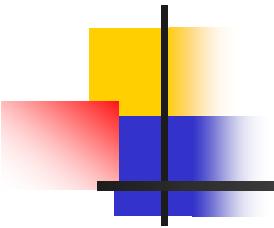
■ Objectives:

- Demonstrate readout of 14.5 m long strip with cooled APD.
 - Build ~ 5 readout boxes with un-optimized Mazda chip and packaged APD's – analog store
 - Build 1 prototype readout box with digital store.
- Design and cost APD readout box
 - Design for manufacturability.
 - Thermal, optical and electrical.
- Refine system cost estimate.
- DAQ specification.

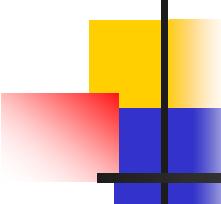


R&D in 2004 - Deliverables

- Readout Modules for readout of 14.4 m tubes.
 - analogue pipeline (MASDA)
 - digital pipeline
- Engineering and Design.
 - Gbit Ethernet on FPGA
 - Clock & Timing system
 - APD box
 - Power distribution system
- Detailed system cost estimate.



The End



APD Box Functions (SAB)

■ Slave and Master APD Box

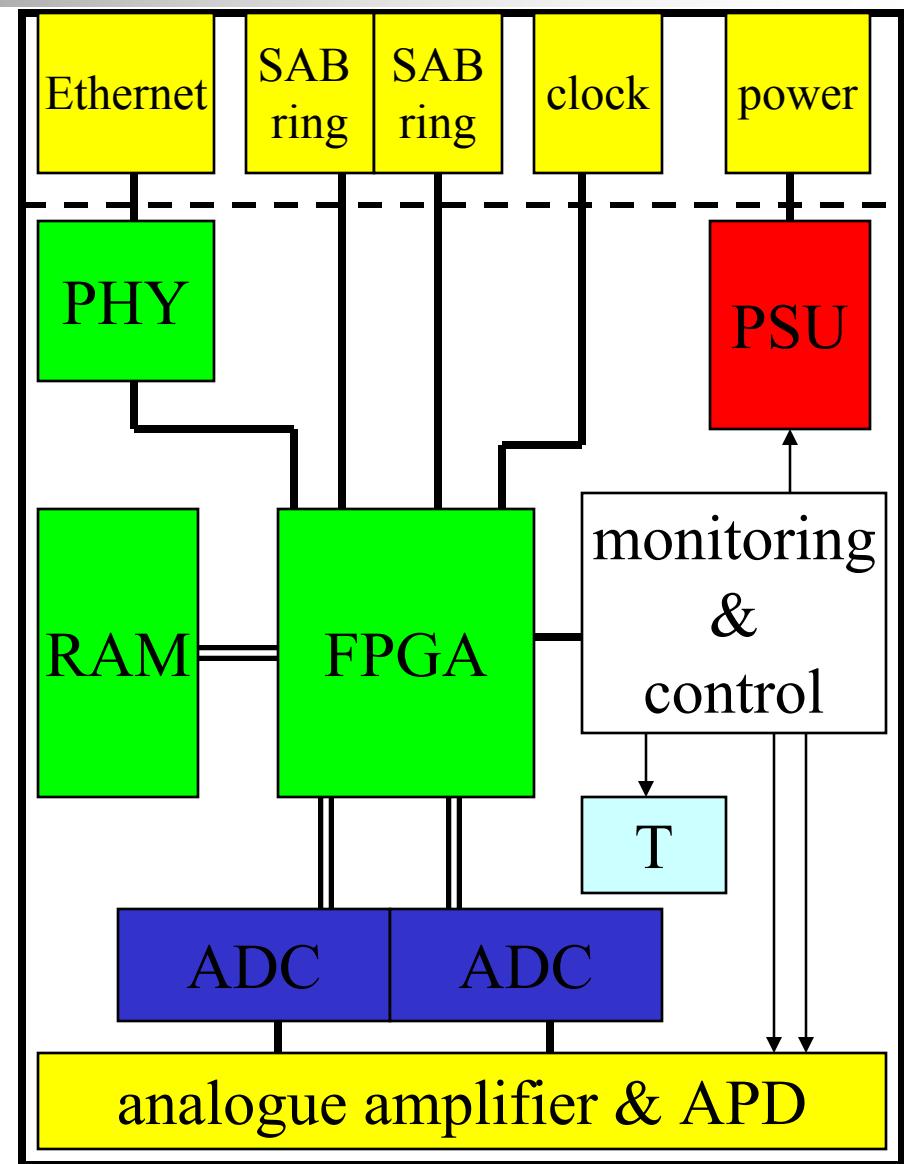
- Receive clock/spill signal
- Digitise/timestamp APD signals
- Sparcify data (zero suppression)
- Transmit data for “spill” on request
- All implemented in FPGA (firmware)

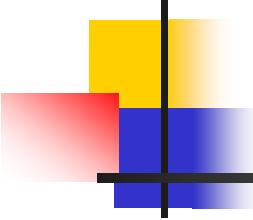
■ Master APD Box only

- Receive clock/ctrl signals from timing system
- Re-transmit clock/ctrl on SAB ring
- Read out SAB via ring
 - SABs are daisy-chained
 - Ring architecture: each SAB can be accessed on either leg
 - Redundancy: save against single SAB failure
- Encapsulate data and transmit it to Readout Concentration Node
- 95 SAB are read out by one MAB (8 planes)

Digital Functionality in APD Box

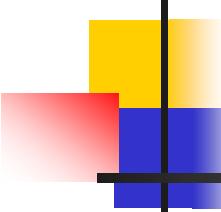
- Ethernet & clock only needed for MAB
- RAM optional
- top part isolated from light-tight box





Readout Concentrator Node (RCN)

- RCN is a standard PC
 - with several network cards
- In Spill mode:
 - Receive data from several 4-16 MABs over Ethernet,
i.e. 8 RCNs needed
 - Traffic shaping and buffering
 - Transmit data to Trigger Processing Nodes
- Also in self-triggering mode (only):
 - Receive trigger primitives/Make L1 trigger decision
 - Broadcast trigger time to MABs & other RCN
 - Receive data for trigger time
 - More RCNs possible



Trigger Farm / Data Merging

- One Master RCN
 - coordinating transfer of data to trigger farm
- Trigger Processing Nodes (TPNs)
 - All detector data together for the first time
 - Run S/W trigger algorithm(s) to identify events
 - Cosmics
 - Beam events
 - ???
- Data Merging node takes data from TPNs for storage
- Can easily take many spill triggers / sec